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Opaque and Transparent Networking

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There is a potential for significant cost, footprint, and power savings by eliminating unnecessary opto-electronic (OE) conversions on a signal path in a core optical mesh network. However, there seems to be some confusion throughout the industry on the benefits of transparent networking (no OE conversions) vs. opaque networking (with OE conversions). In this column we address and clarify some fundamental issues surrounding all-optical networking and all-optical switching.

Introduction

To carry out our assessment of opaque and transparent networks, we make the following basic assumptions on the requirements for core mesh networks:

- Network operators require lowest cost networks not just lowest cost network elements. A network without wavelength conversion in the optical domain and without tunable wavelength access could lead to higher network cost due to inefficient capacity usage even though the network elements may be cheaper than their counterparts with wavelength conversion in the electrical domain.
- A network operator must not be constrained to buy the entire network from a single vendor.
- In order to build a dynamic, scalable, and manageable backbone network it is essential that manual configuration be minimized as much as possible—eliminated if possible. This requires automatic port/neighbor and network topology discovery and other networking functions such as service assurance (e.g., access point performance monitoring for SLA verification), interworking with other network equipment (e.g., keep-alive signal), fault management, and performance management regardless of the switching technology.
- An optical switching system must be easily scalable with low cost and small footprint as the network grows to many hundreds of wavelength channels per fiber and to a speed of 40 Gb/s.

Based on these requirements we identify the challenges faced by completely transparent core mesh networks. The results of this exercise tend to indicate that core mesh networks will remain opaque for some time. This column then explores the potential opportunity for cost reduction and scalability by introducing transparent switches in opaque networks. However, several challenges, both in technology and in network architecture, will have to be addressed before one can achieve the potential benefits of transparent switches.

Network Architectures

Increasing traffic volume due to the introduction of new broadband services is driving carriers to deploy an optical transport layer based on wavelength division multiplexing (WDM). The network infrastructure of existing core networks is currently undergoing a transformation from ring topologies using SONET add/drop multiplexers (ADMs) to mesh topologies utilizing optical cross-connects (OXCs).

A core optical network architecture can be opaque or transparent. An opaque architecture implies that the optical signal carrying traffic undergoes an optical to electronic to optical (OEO) conversion at different places in the network. A transparent architecture implies that the optical signal carrying traffic stays in the optical domain from the time it is generated at the edge of the network until it leaves the network. Figure 1 illustrates three different node architectures that can comprise a reconfigurable core optical network[1]. Architecture 1(a) is an opaque network architecture, as the optical signal undergoes OEO conversions with an opaque (OEO) switch. Architecture 1(b) shows a transparent (OOO) switch between WDM systems with transponders that would be *complemented* by an OEO switch for drop traffic. This is again an opaque network architecture, as the optical signal undergoes OEO conversions at the WDM transponders. Architecture 1(c) shows a completely transparent network topology consisting of transparent optical switches and WDM systems that contain no transponders. The transparent switch would be complemented as in 1(b) by an OEO switch for drop traffic. In architecture 1(c), the signal stays in the optical domain until it exits the network.

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[1] *Architectures based on use of patch-panels are not considered here due to their complete lack of flexibility.*

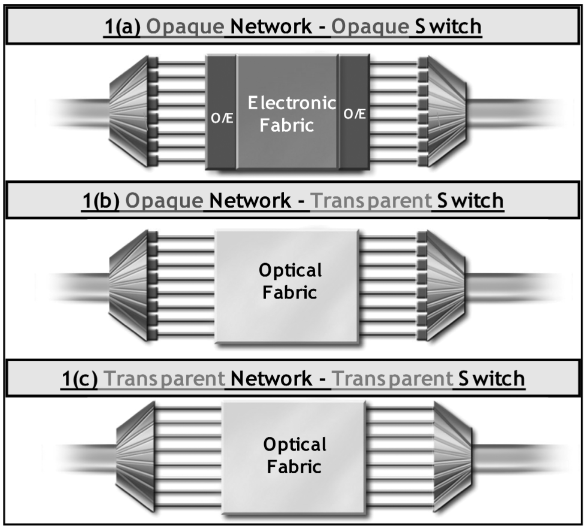

Figure 1: Node architectures for a core optical mesh network.

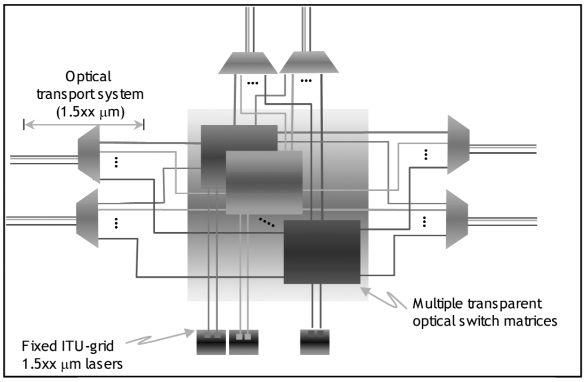

Figure 2: Transparent switch architecture in a transparent network.

Transparent Network Architecture

The transparent network shown in Figure 1(c) and further elaborated in Figure 2 is a seemingly attractive vision. A signal (wavelength) passing through an office does not undergo opto-electronic conversion whereas a client network element (NE), such as a router, interfaces with the switch using long-haul optics to access the WDM equipment without any O/E conversion. On the surface it may appear that such an approach can provide significant footprint, power, and cost savings. Since a signal from a client NE connected via a specific wavelength must remain on the same wavelength when there is no wavelength conversion, only a small size switch fabric is needed to interconnect the WDMs and NEs in a node, which translates to switch scalability. This architecture also implies end-to-end bit rate and data format transparency. While the transparent network architecture may be a viable option for small-scale networks with pre-determined routes and limited number of nodes, it is not likely to be a practical solution for a core mesh network for the following reasons:

- This network does not allow wavelength conversion[2], thus essentially creating a network of *n* (*n* being the number of WDM channels) disjoint layers. Inflexible usage of wavelengths in this network would lead to increased bandwidth and network operational cost thus negating all savings that may result from elimination of opto-electronic conversion. In addition, for this technology to be effective, and in order to build a flexible network for unrestricted routing and restoration capacity sharing, an all-optical 3R-regeneration function must be available. Currently such a technology that can be harnessed in a product does not exist.
- Physical impairments such as chromatic dispersion, polarization mode dispersion (PMD), fiber nonlinearities, polarization-dependent degradations, WDM filter pass-band narrowing, component crosstalk, amplifier noise, etc., accumulate over the physical path of the signal due to the absence of opto-electronic conversion. The accumulation of these impairments requires engineering of end-to-end systems in fixed configurations. It is thus not possible to build a large network with an acceptable degree of flexibility.
- The design of high-capacity DWDM systems is based on intricate proprietary techniques, eluding any hope of interoperability among multiple vendors in the foreseeable future. The interface from the client NE connects through the all-optical switch to the WDM system without O/E conversion, and it is not possible to develop a standard for the interface of a high-capacity WDM. Therefore the operators will not have the flexibility to select the client NE vendor and the WDM vendor independently. Consequently, transparent networks by necessity are single vendor (including the client network elements) solutions that most service providers would not accept, and rightly so.
- In the absence of wavelength conversion, only client-based 1+1 dedicated protection can be easily provided. The wavelength continuity constraint on backup paths makes resource sharing almost impossible in transparent networks and consequently no shared mesh restoration can be easily offered. This in turn means that the capacity requirement for protected services is significantly higher in transparent networks compared to opaque networks.

It is therefore apparent that a number of key carrier requirements—dynamic configuration, wavelength conversion, multi-vendor interoperability of transport equipment (WDM), low network-level cost—are very hard to meet in a transparent network architecture. Therefore, an

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[2] *Our assumption here is that there will be no commercially viable wavelength conversion technology in the optical domain available in the next several years.*

opaque network solution is required to build a dynamic, scalable, and manageable core mesh network. Even though the transparent solution may appear less expensive in terms of equipment costs[3], the opaque network offers the following key ingredients to build a large-scale manageable core mesh network:

(a) No cascading of physical impairments. This eliminates the need to engineer end-to-end systems and allows full flexibility in signal routing.
(b) Multi-vendor interoperability using standard intra-office interfaces.
(c) Wavelength conversion enabled. Network capacity can be utilized for service without any restrictions and additional significant cost savings can be offered by sharing restoration capacity in a mesh architecture.
(d) Support for the management and control functions that are taken for granted in today's networks.
(e) The network size and the length of the lightpaths can be large since regeneration and re-timing is present along the physical path of the signal.

Opaque Network Architecture

Having shown that transparent architectures are inadequate for core mesh networking, we now turn our attention to opaque network architectures in which WDM systems are equipped with transponders. Today's architecture uses opaque switches (with an electronic switch fabric) as part of an opaque network (with transponders present in the WDM system) as depicted in Figure 3. The interfaces to the fabric are opaque, with transceivers providing the OE (input) and EO (output) conversion of the signal. The presence of the transceivers at the edges of the switch fabric enables the switch to access the SONET/SDH overhead bytes for control and management functions. The opaque transceivers thus provide support for fault detection and isolation, performance monitoring, connection verification, neighbor/topology discovery and signaling, as well as support for implementing the network routing and restoration protocols.

The opaque switch approach, however, was faced with a number of challenges when confronted to the (unrealistic) traffic growth projections from just a few years ago: It would eventually reach scaling limitations in signal bit rate, switch matrix port count, and NE cost. These were key motivations behind the attempt to develop large port-count transparent switches.

Figure 4 shows a transparent switch architecture that has no opaque transceiver (TR) cards at its edges. The optical switch fabric is bit-rate independent and it accommodates any data rates available (e.g., OC-48, OC-192, OC-768). The drop-side ports are connected to OEO clients that provide SONET/SDH termination through their opaque ports.

It is important to point out that opaque switches were to remain an integral part of the network architecture in order to provide some key network functions, namely grooming and multiplexing, and to help with SLA verification and control and management.

The promise of optical switching was that, unlike electronic switches, an optical switch fabric's complexity is a flat function, independent of the bit rate and data format of the signals it handles (Figure 5). Moreover, in the long run it was projected that few components would be as small, cheap, and low in power consumption as a silicon micro-mirror in the case of MEMS-based switch fabric.

Transparent switches could thus be expected to scale more easily to high-port count than electronic switches and

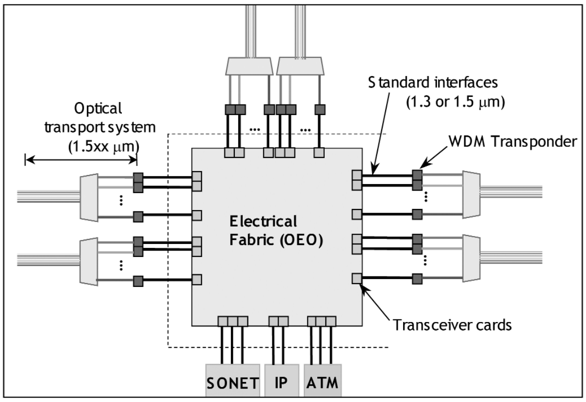

Figure 3: Opaque switch architecture (opaque network).

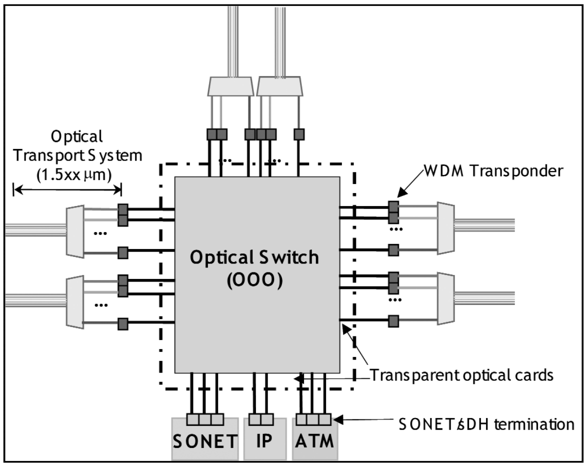

Figure 4: Transparent switch architecture (opaque network).

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[3] *Initially, the cost of transparent networking will remain high due to the cost of research and development and the high cost of manufacturing. Also, OEO solutions continue to decrease in price and fewer elements are required as vendors are pushing the distance between regeneration sites.*

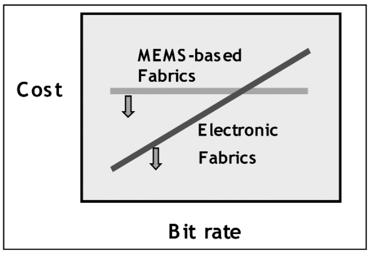

Figure 5: Advantages of optical fabrics.

to become cheaper in terms of the switching fabric and interface card cost compared to opaque switches[4]. This would have resulted in significant cost reduction to network operators because a large amount of the traffic that comes into an office is through traffic (~ 75%) that would be able to bypass the OEO switch. Note, however, that this shift would have only happened on time scales that were gated by the ability of vendors to meet carrier reliability and operational requirements with all-optical technologies such as lightwave micro-machine (for MEMS-based switch fabric) technology [2].

But under today's more realistic traffic growth scenario, and given the lack of deployment of 40 Gb/s WDM systems and the continued decline in price of OEO components, the need for and promise of transparent switches appeared to have moved beyond the foreseeable future. Besides the demise of several of the drivers for high port-count transparent switches, important challenges remain to be solved even in an opaque architecture. Key among them is to provide the control and management functionalities that are readily available with access to the electrical signal and the SONET/SDH overhead bytes.

Network Control & Management for Opaque Networks

Let us now turn our attention to network control and management functions for an opaque network, with opaque or transparent switches.

(I) With opaque switches

Access to the SONET/SDH overhead bytes at the opaque interface cards is a key enabler of network control functionalities. It allows an opaque switch to run port/neighbor and topology discovery protocols and to perform in-band signaling and provisioning functions. The ability of the network to autonomously create and maintain its resource databases is the fundamental building block for an efficient, flexible, and manageable network. The port/neighbor discovery protocol communicates over SONET/SDH overhead bytes to allow the network to create and maintain the port-state and topology databases. Access to the overhead bytes also allows the switches to run mesh restoration protocols. All the network management functionalities also utilize the SONET/SDH overhead bytes at the interface cards. For example, fault detection and performance monitoring take place in the SONET/SDH processors located in the interface cards. Fault isolation relies on the alarms generated by the TR cards after a failure is detected. In addition, read/write access to the SONET/SDH overhead bytes enables the switch to perform connection verification and control in order to avoid misconnections. Finally, since the signal is line terminated at each interface to the switch, unequipped signal is generated per SONET/SDH standards to prevent alarms in other equipment (WDM, router, etc.) connected to the switch.

(II) With transparent switches

Transparent switches essentially help relieve the demand for OEO switch ports and reduce the cost of transporting lightpaths. This is accomplished by having all lightpaths pass through (glass-through) the OOO switches, thus bypassing the OEO switches. The lack of laser transmitters in a transparent switch and the lack of access to the electrical signal and consequently to the overhead bytes at the transparent switch interfaces pose a number of challenges in creating a seamless, interoperable, and manageable network. Approaches to address these challenges principally consist of either deploying OEO cards on the drop side of a transparent switch, or in using and/or relying on the OEO function located at WDM transponders and/or at the opaque client equipment, effectively using these equipment as proxies. Several examples of support for network management and control functions are discussed below.

(a) Automatic port/neighbor and topology discovery

Automatic port/neighbor discovery and topology discovery are key aspects of service provider requirements. Link Management Protocol (LMP) [1] has been proposed to automatically discover (a) node-port associations between the OEO client and the OOO switches and (b) inter-office node-port associations between two neighboring OOO switches. LMP handles transparent switches by using dedicated opaque cards temporarily or the opaque interfaces on the OEO clients and out-of-band signaling to discover connectivity between switches. After the LMP protocol is run and the node-port associations are established, the network topology can be created automatically by a centralized management system or in a distributed way.

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[4] *However, this would not happen until a certain level of mass production of the switch fabric was achieved.*

(b) Performance and fault management

Optical performance monitoring (OPM) can take place at the transparent switch interfaces in the form of optical power monitoring. But electrical performance monitoring can only take place at the OEO endpoints of a lightpath (using the SONET/SDH processors in an opaque card), since there is no signal visibility on transparent switches. With transparent switches, fault localization[5] can take place at the management system by correlating the alarm information generated by the switches. In some cases, fault localization may require alarms generated by the WDM systems as well. In that case, one could essentially use the transponder's access to the electrical signal as a proxy for opaque interfaces in support of control and management functions. In addition, the sequential usage of loopbacks can support fault localization when it is not possible via alarm correlation as proposed with LMP. Looking ahead, if a communication channel between the switches and the WDM systems is implemented, fault localization is expected to be a simpler process. The IETF, the OIF, and the ITU have been considering communication protocols between the OXC and WDM systems to support control and management functions.

(c) Network protection and restoration

Network protection and restoration can be provided in two different ways. Protection and restoration can be supported entirely on the OEO clients of the transparent switches. In this case, the transparent switches are not involved in the protection and restoration process. All the lightpaths and shared back-up channels effectively terminate on the OEO clients. Alternatively, protection and restoration can be supported entirely within the transparent switch-based part of the network with lightpaths and shared back-up channels terminating on transparent switches. The restoration crossconnects are then performed by the transparent switches upon appropriate triggering (such as signal failure or signal degrade conditions) coming, for example, from the OEO switches through a control link. For transparent switches to directly support shared mesh restoration, the provisioned shared back-up channels (when not in use) require the presence of an unequipped signal. This is because the lack of unequipped (keep-alive) signal results in the following undesirable behaviors: (a) alarms generated at the WDM systems that have knowledge of provisioned channels but detect no light on those channels, (b) lack of monitoring of the restoration channels to ensure availability when/if a failure occurs and (c) increased restoration time if a failure occurs, due to the additional time required to turn on the ITU grid WDM lasers. An out-of-band communication protocol between the OXC and WDM systems can be used to "work around" this issue by suppressing alarms and keeping the lasers up even in the absence of keep-alive signals on provisioned but not in-use channels. An alternative would have dedicated OEO cards reside on the transparent switch and inject signals on back-up channels to prevent alarms and keep the WDM laser on.

(d) Loss budget management

An important operational issue associated with a transparent switch is power budget management. Because of the relatively high insertion loss of an optical switch fabric and the resulting loss from input port to output port, traditionally deployed cross-office optics cannot be supported with a transparent switch. Therefore, deployment of transparent switches requires higher-cost, cross-office optics or new low-cost optics such as those currently being specified in the OIF.

Conclusion

This column has presented and analyzed opaque and transparent architectures for core mesh networks. While completely transparent core mesh networks are still far off on the horizon, the drivers of a few years ago for high port-count transparent switches have mostly disappeared. In addition, their deployment in opaque networks would still face technological as well as control and management challenges that remain to be solved. Thus, opaque networks and opaque switches still have a bright future as the supporting infrastructure of core mesh optical networks.

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REFERENCES

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[5] *As long as the restoration mechanism is triggered quickly, fault isolation need not be an instantaneous process.*